PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H01L 21/60, 21/58, H05H 1/18

A1

(11) International Publication Number: WO 96/17378

(43) International Publication Date: 6 June 1996 (06.06.96)

(21) International Application Number: PCT/US95/14909

(22) International Filing Date: 13 November 1995 (13.11.95)

(30) Priority Data:

08/340,144	15 November 1994 (15.11.94)	US
PCT/US94/13373	16 November 1994 (16.11.94)	WO
(34) Countries for which the regional or international application was filed:		CA et al.
08/452,255	26 May 1995 (26.05.95)	US
08/457,479	1 June 1995 (01.06.95)	US
08/526,246	21 September 1995 (21.09.95)	US
08/533,584	18 October 1995 (18.10.95)	US
08/554,902	9 November 1995 (09.11.95)	US

(71) Applicant: FORMFACTOR, INC. [US/US]; 2130 Research Drive, Livermore, CA 94550 (US).

(72) Inventors: KHANDROS, Igor, Y.; 25 Haciendas Road, Orinda, CA 94563 (US). MATHIEU, Gaetan, L.; Apartment 203, 7980 Fall Creek Road, Dublin, CA 94568 (US). ELDRIDGE, Benjamin, N.; 11 High Ridge Road, Hopewell Junction, NY 12533 (US). GRUBE, Gary, W.; R.D. 2, Box M-397, Monroe, NY 10950 (US).

(74) Agent: LINDEN, Gerald, E.; Suite 300, 2716 South Chickasaw Trail, Orlando, FL 32829 (US).

(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TT, UA, UG, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG), ARIPO patent (KE, LS, MW, SD, SZ, UG).

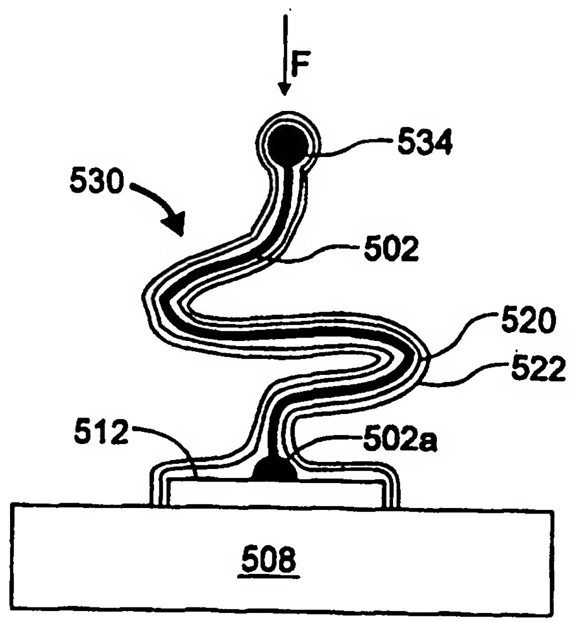
Published

With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: ELECTRICAL CONTACT STRUCTURES FROM FLEXIBLE WIRE

(57) Abstract

Contact structures exhibiting resilience or compliance for a variety of electronic components are formed by bonding a free end of a wire (502) to a substrate (508), configuring the wire (530) into a wire stem (530) having a springable shape, severing the wire stem (530), and overcoating the wire stem (530) with at least one layer of a material (522). In an exemplary embodiment, a free end of a wire stem (530) is bonded to a contact area on a substrate (508), the wire stem (530) is configured to have a springable shape, the wire stem (530) is severed to be free-standing by an electrical discharge, and the free-standing wire stem is overcoated by plating. A variety of materials for the wire stem (530) (which serves as a falsework) and for the overcoat (540) (which serves as a superstructure over the falsework) are disclosed. The resilient contact structures described herein are ideal for making a "temporary" (probe) connections to an electronic component such as a semiconductor die, for burn-in and functional testing.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	GB	United Kingdom	MR	Mauritania
AU	Australia	GE	Georgia	MW	Malawi
BB	Barbados	GN	Guinea	NE	Niger
BE	Belgium	GR	Greece	NL	Netherlands
BF	Burkina Faso	HU	Hungary	NO	Norway
BG	Bulgaria	IE	Ireland	NZ	New Zealand
BJ	Benin	IT	Italy	PL	Poland
BR	Brazil	JP	Japan	PT	Portugal
BY	Belarus	KE	Kenya	RO	Romania
CA	Canada	KG	Kyrgystan	RU	Russian Federation
CF	Central African Republic	KP	Democratic People's Republic of Korea	SD	Sudan
CG	Congo			SE	Sweden
CH	Switzerland	KR	Republic of Korea	SI	Slovenia
CI	Côte d'Ivoire	KZ	Kazakhstan	SK	Slovakia
CM	Cameroon	LI	Liechtenstein	SN	Senegal
CN	China	LK	Sri Lanka	TD	Chad
CS	Czechoslovakia	LU	Luxembourg	TG	Togo
CZ	Czech Republic	LV	Latvia	TJ	Tajikistan
DE	Germany	MC	Monaco	TT	Trinidad and Tobago
DK	Denmark	MD	Republic of Moldova	UA	Ukraine
ES	Spain	MG	Madagascar	US	United States of America
FI	Finland	ML	Mali	UZ	Uzbekistan
FR	France	MN	Mongolia	VN	Viet Nam
GA	Gabon				

TITLE

ELECTRICAL CONTACT STRUCTURES FROM FLEXIBLE WIRE

TECHNICAL FIELD OF THE INVENTION

The invention relates to contact structures for making electrical connections to, from and between electronic components, especially microelectronic components and, more particularly, to contact structures exhibiting resiliency and/or compliance.

CROSS-REFERENCE TO RELATED APPLICATIONS

This is a continuation-in-part of commonly-owned, copending U.S. Patent Application No. 08/340,144, filed 11/15/94 (status pending) and its counterpart PCT Patent Application No. PCT/US94/13373, filed 11/16/94 (status pending; collectively, the US and PCT parent cases are referred to hereinafter as "CASE-2"), both of which are continuations-in-part of commonly-owned, copending U.S. Patent Application No. 08/512,812, filed 11/16/93 (status pending; referred to hereinafter as "CASE-1").

BACKGROUND OF THE INVENTION

Due to its superior conductive and non-corrosive characteristics, gold is a "material of choice" for making electrical connections between electronic components. For example, it is well known to make a plurality of wire bond connections between conductive pads on a semiconductor die and inner ends of leadframe fingers. This is cited as one example of making permanent connections between a first, "active" electronic component (the die) and a second "passive" electronic component (the leadframe).

The present invention advantageously employs wire-bonding equipment in which, generally, wire (e.g., gold wire) is supplied from a spool through a capillary (also referred to as a "bonding head") and is bonded to a substrate. Generally, the nature of the bonding head will be determined by the nature of the bond to be made thereby. When the bonding head is for making a ball bond, it will generally be a "capillary". When the bonding head is for making a wedge bond, it will generally be a "wedge", these terms having recognized meanings in the art. To simplify matters, in the main hereinafter, the term "capillary" will be employed to indicate a bonding head suitable for making either ball or wedge bonds, applying thermal energy

and/or compression during bonding.

The following US patents (cited, when applicable, by patent number, first named inventor, month/year of issue, and US Class/Subclass), incorporated by reference herein, are indicative of the state of the art of wirebonding:

(a) U.S. Patent No. 5,110,032 (Akiyama, et al.; 5/92; USCL 228/102), entitled METHOD AND APPARATUS FOR WIRE BONDING, discloses wire (13) supplied from a wire spool (12) through a capillary (10). (In this patent, the wire 13 is insulated.) A control unit (20) is shown which includes a CPU (processor) and a memory unit (storage for software commands). The control unit exercises control over movement of the capillary, and over a discharge power circuit (18) which, in conjunction with a discharging electrode (17) is used to sever the wire with a discharge voltage.

(b) U.S. Patent No. 3,460,238 (Christy, et al.; 8/69; USCL 227/111), entitled WIRE SEVERING IN WIRE BONDING MACHINES, is directed to a technique whereby the wire severing operation in a wirebonder comprises moving the bonding needle (or "capillary", as used herein) with holding pressure sufficient to frictionally engage the wire and insufficient to deform the wire away from the bond area. This patent is cited as exemplary of the fact that wire-bonding has been known for decades, and also of the fact that it is generally undesirable to "deform" the wire while moving the capillary.

(c) U.S. Patent No. 5,095,187 (Gliga; 3/92; USCL 219/68), entitled WEAKENING WIRE SUPPLIED THROUGH A WIRE BONDER, discloses wire-bonding techniques wherein a wire is bonded to a contact on an electronic component by the application of one or a combination of heat, pressure and vibration. This patent discusses weakening or severing the wire by localized

application of heat, and how the severing operation may result in a broadened portion on the severed end of the wire. The severing heat may be applied to the wire by means of an electrode from which an electric field can be made to extend to the wire such that an arc is created between the electrode and the wire. This patent describes a severing technique wherein a first portion of the arc is of a first polarity for weakening of the wire, and a second portion of the arc is of a reverse polarity for controlling dispersion of charged particles emitted from the wire.

(d) U.S. Patent No. 4,860,433 (Miura; 8/89; USCL 29/605), entitled METHOD OF MANUFACTURING AN INDUCTANCE ELEMENT, discloses a technique of winding a coil of fine copper wire on a spool member on a substrate. The copper wire is insulated. It is known that the insulation will be removed from the end of the wire when an electronic flame off (EFO) spark severs the wire, such as at the conclusion of making a previous bond. An end portion of the wire is bonded to a conductive path on the substrate. Then, either the capillary or the substrate is rotated, and a table supporting the substrate may be moved in the vertical direction, to wind the coil of fine copper wire on the spool member. Finally, an opposite end portion of the wire is bonded to another conductive path on the substrate.

Packaging is another milieu (field of endeavor) wherein it is important to effect a plurality of electrical connections between a first electronic component and a second electronic component. For example, in a ceramic package, a semiconductor die is disposed in a cavity in a ceramic package and (typically) wire-bonded to conductive traces extending into the cavity. A plurality (e.g., an array) of pins are disposed on an external surface of the package, and the pins connected by internal traces (patterned conductive layers) and vias to the conductive traces extending into the cavity. The package may then be

mounted to a printed circuit board (PCB) having a corresponding plurality (e.g., array) of holes, each hole receiving a corresponding one of the package pins. The pins are typically soldered to the plated-through holes in the PCB to effect a permanent connection between the first electronic component (the packaged semiconductor device) and the second electronic component (the PCB). Alternatively, the package may be received by a socket having a corresponding plurality (e.g., array) of holes, each hole receiving one of the package pins, to effect a temporary connection between the first electronic component (packaged semiconductor device) and the second electronic component (socket).

It is generally well known to protect semiconductor devices against moisture. To this end, various packages exhibit various degrees of hermeticity - ceramic packages generally providing superior protection against the environment at relatively high cost, plastic (e.g., resin) and PCB-type (encapsulated) packages exhibiting relatively poor protection against the environment at relatively low cost, to name a few. In order to have the "the best of both worlds" - namely good hermeticity at low cost, it is known to coat bond wires and their surrounding connections (to the die and to a leadframe, e.g.). One example is found in U.S. Patent No. 4,821,148 (Kobayashi, et al., 4/ 89; USCL 361/392), entitled RESIN PACKAGED SEMICONDUCTOR DEVICE HAVING A PROTECTIVE LAYER MEAD OF A METAL-ORGANIC COMPOUND. In this patent, a silver electrode (4) on a leadframe (2) is bonded to an aluminum electrode (5) on a silicon chip (1). The resulting assembly is immersed in a solution of benzotriazole (BTA) in ethyl alcohol. An Ag-BTA film is formed on the surface of the silver electrode, an Al-BTA film is formed on the surface of the aluminum electrode, and a Cu-BTA film is formed on the surface of the copper wire. These three metal-BTA films protect the wire and the electrodes from damage by (environmental) dampness. Notably, in this patent, it is immaterial, at best, whether the

metal-BTA films are conductive, interconnection (of die to leadframe) having previously (prior to coating) been achieved by the wire bond itself. Preferably, such a "hermetic" coating would not be conductive, as it would tend to short out the device (die).

Pins, i.e. elongated rigid electrically-conductive elements, are well known, and are generally brazed to pads on electronic packages (including chip carriers).

U.S. Patent No. 3,373,481 (Lins, et al.; 3/68; USCL 29/471.3), entitled METHOD OF ELECTRICALLY INTERCONNECTING CONDUCTORS, discloses forming pin-like gold pedestal structures (13) atop terminal portions (12) of an integrated circuit device (10) by thermocompressing gold spheres (13, see Figure 2) and shaping the spheres with a heated vacuum holder (14). The use of an ultrasonic bonder in lieu of the vacuum holder is discussed. As shown in Figure 3 of the patent, a bond is formed between the pedestal structure (13) and what appears (in the side view) to be the entire surface of the terminal (12).

U.S. Patent No. 4,418,857 (Ainslie, et al.; 12/83; USCL 228/124), entitled HIGH MELTING POINT PROCESS FOR AU:SN:80:20 BRAZING ALLOY FOR CHIP CARRIERS, discloses an exemplary technique for brazing pins to chip carrying substrates.

U.S. Patent No. 4,914,814 (Behun, et al.; 4/90; USCL 29/843), entitled PROCESS OF FABRICATING A CIRCUIT PACKAGE, discloses filling an array of pin holes in a pin mold with lead/tin solder, which array of pin holes is in substantial registration with an array of conductive pads on one side of a chip carrier, heating the lead-tin solder in the pin mold such that the solder becomes molten and coalesces with the array of conductive pads on the chip carrier, thereby forming an array of miniature "pins" bonded to the array of conductive pads on

the chip carrier. This permits the formation of elongated, solder terminals of controlled height and, apparently, of relatively high aspect ratio.

U.S. Patent No. 4,955,523 (Carlomagno, et al.; 9/90; USCL 228/179), entitled INTERCONNECTION OF ELECTRONIC COMPONENTS, discloses a technique for interconnecting electronic components in which interconnection wires are bonded to contacts on a first component (such as a semiconductor die (1)) without the use of a material other than the materials of the contacts and the wires. The wires are then severed to a desired length of between two to twenty times the wire diameter (2d to 20d), and bonded to contacts on a second component (21) by means of a conductive material such as solder. The wires, once bonded to the first component, are severed at their desired length (by the bonding head (9) of a wirebonder) via an aperture (13) in the side wall of the bonding head. To this end, an electrode (51) is inserted into the aperture (13). As shown in this patent, the free-standing wires (7) have their ends inserted into pools (27) of conductive material such as solder in recesses of the second component. See also U.S. Patent No. 5,189,507 (Carlomagno, et al.; 2/93; USCL 257/777), also entitled INTERCONNECTION OF ELECTRONIC COMPONENTS.

Surface mount technology solves certain problems associated with making interconnections between electronic components, but has proven itself not to be the panacea it was once envisioned to be. Generally, in surface mount technology (SMT), including flip-chip technology, solder bumps are formed on a face of a first electronic component, pads are provided on a face of a second electronic component, and the components are brought together, face-to-face, after which heat is applied to reflow the solder of the solder bumps. The challenges to effecting reliable surface mount include forming solder bumps with controlled geometry and high aspect ratio (ration of height to

width), sometimes referred to as "solder columns"..

U.S. Patent No. 5,130,779 (Agarwala, et al.; 7/92 USCL 357/67), entitled SOLDER MASS HAVING CONDUCTIVE ENCAPSULATING ARRANGEMENT, describes "elongated" solder columns having high aspect ratios. On an "electronic carrier" (substrate), a pad is formed on which a first solder mass is deposited and capped with a metal layer. An additional (second) solder mass is formed atop the first solder mass. An additional (third) solder mass may be formed atop the second solder mass.

Burn-in and testing is another field of endeavor which employs a plurality of temporary connections to be made between a first electronic component such as a semiconductor die and a second electronic component such as a test card. As discussed in greater detail hereinbelow, this typically involves first packaging the semiconductor die, and contacting pins on the package with special test fixtures such as a "bed of nails" (array of springy pins) arranged in a pattern corresponding to the pattern of pins on the semiconductor package. The manufacture of such test fixtures is a specialty requiring a different test fixture for each array pattern, and is consequently both expensive and time-consuming.

Making resilient interconnections between electronic components is generally known to be desirable, and has been the object of prolonged endeavor. Often (e.g., typically), external connections to semiconductors devices are relatively rigid pins disposed on an exterior surface of a package. Some effort has been made in the past to implement resilient interconnection structures. In some instances, resilient connections have been effected with metal elements. In other instances, resilient connections have been effected with a combination of metallic elements and elastomeric elements.

One recent effort directed to making resilient connections is described in an article entitled ELASTOMERIC CONNECTOR FOR MCM AND TEST APPLICATIONS, ICEMM Proceedings, 1993, pages 341-346, which describes an "Elasticon" (tm) connector. The Elasticon connector uses solid gold or gold alloy wires for the conductive elements, embedded in an elastomer material (e.g., liquid elastomer resin injected into a mold cavity), and is generally targeted at the interconnection requirements for land grid array (LGA) packages for multichip (MCM) and single (SCM) chip modules. The size, shape and spacing of the wires, along with the elastomer material properties, can be tailored to specific application requirements which include MCM and SCM packaging, board-to-board and cable-to-board interconnections, as well as high density PCB and IC chip testing applications. The solid gold wires and the silicone elastomer material are impervious to corrosion. Figure 1 of the article illustrates a basic embodiment of the Elasticon connector, wherein a plurality of wires are ball-bonded to a rigid substrate and extend straight at an angle (e.g., 45-85°) from the surface of the substrate. Attachment of the proximal ends of the wires to the substrate is by an angled flying lead wire bonding process using compressive force and ultrasonic energy applied through the capillary tip and thermal energy applied through the heated stage on the wirebonder. The capillary and substrate are positioned to allow a shear blade mechanism to sever the wire at the desired height and angle from the substrate surface. Electronic flame-off (EFO) is used to melt the wire extending from the capillary tip to start the next ball bond (of the proximal end of the next wire to be bonded to the substrate). After mounting all of the wires to the substrate, a ball-shaped contact is formed at the far (distal) end of each wire by a process of laser ball forming, and the plurality of wires are embedded in an elastomer material. The ball-shaped (enlarged) distal ends help prevent the wires from vibrating loose and causing shorts between contacts. As noted in the article, the

angled orientation of the conductors is necessary to minimize plastic deformation of the wires as an Elasticon connector is compressed between two parallel surfaces. The angled orientation also provides a "wiping" contact surface which, when the connector is compressed, will cause the wires to rotate and slide against the mating contact surfaces. The article discusses the use of gold/palladium alloys and platinum for the wires. Figure 3 of the article describes clustering wires in groups of one to four wires per contact, in conjunction with forming grooves in the elastomer between each group of wires. The various embodiments of the Elasticon connector described in the article require a substrate of ceramic, metal, silicon or epoxy-glass laminate material, and interposer embodiments require an etchable substrate material such as copper with a thin layer of gold on the top surface. Figure 8 of the article describes integrated probe contacts and aptly notes that the ability to test for known good dies has been one of the stumbling blocks for MCM packaging. As shown therein, a probe matrix uses 2 mil (0.002 inch) diameter gold wires in an array. The probes can permanently be attached to the test module, or fabricated as an interposer structure. U.S. Patent No. 5,386,344 (Beaman, et al.; 1/95; USCL 361/785), entitled FLEX CIRCUIT CARD ELASTOMERIC CABLE CONNECTOR ASSEMBLY, discloses a related "Elastipac" (tm) elastomeric cable connector.

Another illustrative effort at making resilient connections may be found in U.S. Patent No. 5,299,939 (Walker, et al.; 4/94; USCL 439/74), entitled SPRING ARRAY CONNECTOR, which discloses independently bendable springs with significant horizontal elasticity, including sine, helix, cantilever, and buckling beam shapes in sheet and wire forms. A connector formed thereby provides substantial compliance in order to provide compensation for variations, including manufacturing tolerances, alignment tolerances, and thermo-mechanical expansion. Fabrication of the spring connectors proceeds generally as follows. A three-

dimensional mandrel defines the inner surface shape of the spring (12). An insulating layer (50) is applied on the spring (12). A conducting layer (14) is applied on the insulating layer at predetermined locations. A plurality of springs (12) are formed as a unitary sheet layer of resilient material (38), which can readily be deposited (on the mandrel), such as nickel 96%-phosphorous 4% and nickel 97%-cobalt 3%. The mandrel is removed after depositing the spring layer (38). Alternatively, the mandrel may be "sacrificial", such as is known in the art of "lost wax" casting". Using a resilient wire as the spring layer (e.g., as an alternative to using a sheet) is discussed, and includes a wire (204), covered by an insulating layer (21), covered by a segmented conductive layer (212), covered by an outer insulating layer (214). The resulting spring connector is principally (if not solely) directed to making contact (versus attachment). As aptly set forth in the patent:

> "a distinction must be made between two types of electrical connection: attachment and contact. Attachment is [a] relatively permanent connection and typically involves a durable metallic connection, such as solder, micro-brazing or micro-welding connection. Contact is a relatively temporary connection and implies a segmented connection between mating conductors, usually dependent upon a compressive force without the presence of a durable metallic connection."

Another illustrative effort at making resilient connections may be found in U.S. Patent No. 4,067,104 (Tracy; 1/78; USCL 29/626), entitled METHOD OF FABRICATING AN ARRAY OF FLEXIBLE METAL INTERCONNECTS FOR COUPLING MICROELECTRONIC COMPONENTS. This patent discloses fabricating an array of cylindrical columns, such as several layers of indium, on active devices, such as semiconductors, wherein the columns can flex to

accommodate differential thermal expansion.

U.S. Patent No. 4,793,814 (Zifcak, et al.; 12/88; USCL 439/66), entitled ELECTRICAL CIRCUIT BOARD INTERCONNECT, discloses a connector arrangement for providing electrical interconnection between corresponding contact pads of opposed first and second circuit boards and includes an electrically nonconductive support member which includes resilient elastomeric material. An electrically conductive interconnect element extends through the thickness of the support and has a pair of pad engagement surfaces disposed to engage the respective contact pads.

U.S. Patent No. 4,330,165 (Sado; 5/82; USCL 339/59), entitled PRESS-CONTACT TYPE INTERCONNECTIONS, discloses an interconnector composed of an elongated rod member (1) made of a rubbery elastomer, a plurality of linear electrically conductive bodies (2) embedded in the rod member (1), and two sheet members (3,3) bonded to the lateral surfaces of the rod member (1). The ends of the linear bodies (2) appear on the opposite surfaces, i.e. the top surface and the bottom surface, of the rod member (1), forming the contacting surfaces with the circuit boards between which the interconnector is to be mounted as sandwiched. The linear conductive bodies (2) are each a ribbon of, for example, a metal.

U.S. Patent No. 4,295,700 (Sado; 10/81; USCL 339/61), entitled INTERCONNECTORS, discloses a press-type interconnector having rectangular connecting piece made of a sheet or film of elastic material, which is an assembly of alternating electroconductive elastic material and electrically-insulating material so that the rectangular piece, as a whole, has a plurality of electrically conductive paths (i.e., the electroconductive stripes). The rectangular connecting piece is sandwiched between two holding members which are made of an

insulating material.

U.S. Patent No. 3,795,037 (Luttmer; 5/74; USCL 29/628), entitled ELECTRICAL CONNECTOR DEVICES, discloses a plurality of bent or curved elongated flexible conductors embedded in, and extending between surfaces of a block of elastomeric insulating material. Exemplary flexible conductors are formed from any suitable electrically conductive resilient material such as, for example, phosphor bronze, and have exemplary cross-sectional dimensions on the order of 25 microns (μm), and may have a free length of 2 mm (millimeters).

U.S. Patent No. 5,067,007 (Kanji, et al.; 11/91; USCL 357/54), entitled SEMICONDUCTOR DEVICE HAVING LEADS FOR MOUNTING TO A SURFACE OF A PRINTED CIRCUIT BOARD, discloses improving the reliability of surface-mount type packages so that when the packages are mounted to a wiring substrate the lead pins that receive load from the axial direction exhibit bending strength which is smaller than the junction strength at the junction portions. To achieve this object, the lead pins are made of a material having large resiliency such as fiber-reinforced material, a transformation pseudo elastic material, an ultra-high tension material, or a heat-resistant ultra-high tension material. This patent also points out the problem that, in the case of pin grid array (PGA) packages, all of the pins are not necessarily of the same length - the result of which is that some of the pins may not contact pads (e.g., on a test substrate). Figures 7A and 7B of this patent are of particular interest, wherein pins (20) have a particular shape and are formed of a particular material. The pins (20 are made of a material having Young's modulus of smaller than $15x10^{10}$ Pa, and have their central portions curved in an arcuate form such that the displacement from the axial (straight) direction becomes greater than one half the diameter of the pins. Examples of materials satisfying the Young's modulus criteria are: highly

pure copper (Cu), highly pure iron (Fe), highly pure nickel (Ni), copper alloy, and a composite wire comprising of a stringly (sic) resilient fine wire bundled with a soft metal such as copper as a binding material. With such a shape, and being formed of such materials, the deformation strength (yield strength) of the pins becomes smaller than the junction strength of either the brazing material (12, holding the pin to the package) or the solder (13, connecting the pin to the PCB). When thermal or mechanical stresses are exerted on the pins, they undergo elastic deformation to reduce the stress. In an exemplary embodiment shown in Figure 1D and described with respect thereto, tungsten (W) molybdenum, carbon amorphous metal and fine wires having large resiliency are described. The fine wire may be a composite wire (11A) which is bundled together with a soft metal such as copper as the binding material. The composite wire has a plating (11B) which comprises gold (Au) or gold/nickel. Gold, as discussed hereinabove, is very soft, and inherently not resilient. As specifically mentioned in this patent, "the thickness of the plating is so small that the effect to the bending strength [of the composite wire 11A] can be neglected. The plating is effected for the purpose of easy soldering and, concretely (sic), has a thickness of 1 to 4 μm for nickel and 0.1 to 1 μm for gold." (see paragraph bridging columns 7-8).

U.S. Patent No. 5,366,380 (Reymond; 11/94; USCL 439/66), entitled SPRING BIASED TAPERED CONTACT ELEMENTS FOR ELECTRICAL CONNECTORS AND INTEGRATED CIRCUIT PACKAGES, discloses a contact element for an electrical connector of for an integrated circuit package (ICP), which is particularly useful for surface mount applications. The contact element has a base portion, a spring portion having at least partially helical spring elements, and a tapered contact portion which mates in a biased manner with a conductive rim of a hole, and can be fabricated from a flat sheet with punching, rolling, and/or forming operations, thin-

walled drawn parts, or modular parts. The contact elements are maintained in a compressed state by a hold-down mechanism. The contact elements can be associated with insulating housings and/or spacers which provide functions such as alignment, compression limitation, contact support, and installation fixturing.

U.S. Patent No. 4,764,848 (Simpson; 8/88; USCL 361/408), entitled SURFACE MOUNTED ARRAY STRAIN RELIEF DEVICE, discloses mounting "roots" of relatively-thin pin-like electrical conductors (22) extending through pin holes in a substrate (16) to which an integrated circuit chip or similar electronic component or device (18) is mounted. The pins (22) are fabricated of an electrically conductive material such as copper, and each pin has at least two bends between its root and its tip for providing strain relief when the tip of the pin is connected to a surface.

U.S. Patent No. 5,317,479 (Pai, et al.; 5/94; USCL 361/773), entitled PLATED COMPLIANT LEAD, discloses a curved lead which provides a mechanical and electrical connection between a board contact on a circuit board and a chip contact associated with a circuit chip. The curved lead is substantially entirely plated with solder, and is formed of a single piece of conductive material. Generally, the curved lead has two parallel surfaces, one for connecting with the chip contact and one for connecting with the board contact, and at least one curved portion therebetween. The leads are preferably formed from a thin strip of material and, for example, may be 0.018 inches wide and 0.070 inches in overall (e.g., prior to bending) length, and are preferably formed of thick copper beryllium and cobalt alloy 0.003 - 0.005 inches thick. The lead is covered with solder in a manner which is carefully controlled so that excess solder does not interfere with the desired compliance of the lead.

U.S. Patent No. 4,989,069 (Hawkins; 1/91; USCL 357/74), entitled SEMICONDUCTOR PACKAGE HAVING LEADS THAT BREAK-AWAY FROM SUPPORTS, discloses a stress buffer frame (16) having flexible metal leads (26) reducing stress caused by the differing coefficients of thermal expansion of a semiconductor package and a printed circuit or the like on which the package is mounted. The leads are essentially flat ribbon-like leads, which are bent to extend away from the buffer frame, then bent again to have a portion (32) parallel to the buffer frame. Nickel/iron alloy is discussed as a material for the frame (and leads thereof).

One reason to provide a degree of compliance in electrical connections is to absorb stresses which occur due to thermal cycling. Generally, as a semiconductor device (die) operates, it generates heat. This causes the die to expand, often at a different rate than the package in which the die is mounted and, similarly, at a different rate than the electrical connections between the package and the die. (Assuming that the heat generated by the die is fairly uniform throughout the die, the die will tend to expand about its centroid, or center of symmetry.) This is similarly the case with surface mounted dies, with the die expanding at a different rate than the board to which it is mounted (and the electrical connections between the die and the board). The difference in thermal coefficients of expansion between the die and surrounding elements (e.g., package, board, electrical connections) results in mechanical stress. Generally, it is desired to account for, and to reduce, such thermally-induced mechanical stresses. For example, U.S. Patent No. 4,777,564 (Derfiny, et al.; 10/88; USCL 361/405), entitled LEADFORM FOR USE WITH SURFACE MOUNTED COMPONENTS, discloses an electrical connection extending from an electronic component and connecting to a printed circuit board which is highly resistant to stress-related failures resulting from thermal cycling.

U.S. Patent No. 5,086,337 (Noro, et al., 2/92; USCL 357/79), entitled CONNECTING STRUCTURE OF ELECTRONIC PART AND ELECTRONIC DEVICE USING THE STRUCTURE, discusses the desirability of having deformability (freedom) and "flexibility" (spring property) in a perpendicular (z) direction at the junctions between LSI chips (semiconductor dies having Large Scale Integration) and a wiring substrate. (see, e.g., column 4, lines 50-55). This patent discloses a connecting structure for electrically connecting an electronic part, such as an LSI chip, to a substrate, such as a wiring substrate, having an absorption function of the difference of thermal expansion in a horizontal direction (e.g., in the plane of the chip) and capability of displacement in a vertical (z-axis) direction. A representative embodiment of the connecting structure is shown in Figures 2(a), 2(b) and 2(c), wherein the connecting structure is in the form of a flat, spiral spring, a one end of the flat spiral spring being connected to a one electronic component, and another end of the flat spiral spring is connected to another electronic component. This allows for displacement of the two components in the z-axis, while maintaining a connection therebetween. The flat, spiral spring connectors are generally formed as a Cr-Cu-Cr "sandwich", which is annealed and coated with Au to improve its solder-wettability (Cr being comparatively non-wettable as compared with Au). See also U.S. Patent No. 4,893,172 (Matsumoto, et al.; 1/90; USCL 357/79), entitled CONNECTING STRUCTURE FOR ELECTRONIC PART AND METHOD OF MANUFACTURING THE SAME. (It should be noted that, in the present patent application, the term "flexibility" is generally associated with plasticity, and that the term "resiliency" is generally associated with springiness.)

As a general proposition, it is much easier to fabricate a resilient contact structure on electronic components other than semiconductor dies, due to the fragility (delicate nature)

of semiconductor dies. This has led to the development of "passive" electronic components which have resilient contact structures incorporated therein and which, in use, are disposed (i.e., interposed) between two electronic components having corresponding contact pads.

U.S. Patent No. 4,642,889 (Grabbe; 2/87; USCL 29/840), entitled COMPLIANT INTERCONNECTION AND METHOD THEREFOR, discloses placing an interposer having interconnect areas between a circuit board and a device to be surface mounted with interconnect areas disposed between conductive strips on the circuit board and pads contained on the surface mount device. The interconnect area of the interposer has disposed therein a plurality of fine wires having flux and solder. The desirability of having a high solder pedestal so that substantial compliance will be available to compensate for thermal coefficient of expansion mismatch ("potato-chipping") is disclosed, as well as the desirability of implementing such high solder pedestals in an interposer.

U.S. Patent No. 3,509,270 (Dube, et al.; 4/70; USCL 29/625), entitled INTERCONNECTION FOR PRINTED CIRCUITS AND METHOD OF MAKING SAME, discloses an insulating body (2) having an aperture (4) extending therethrough with a compression spring (6) inserted therein. The insulating body, with springs inserted into its apertures and extending out of the apertures, is sandwiched between two electrically conducting circuit members (8, 10), which are bonded to the insulating body with resin layers (12). The springs are disclosed as being made of gold alloy containing platinum, silver, copper and zinc, and may be provided with a coating of solder.

U.S. Patent No. 3,616,532 (Beck; 11/71; USCL 174/68.5), entitled MULTILAYER PRINTED CIRCUIT ELECTRICAL INTERCONNECTION DEVICE, discloses a similar (to Dube, et al.) interconnection

arrangement, wherein coil springs are compressed and inserted into a pot of molten solder, and subsequently withdrawn from the pot and the solder allowed to solidify to thereby hold the coils of the compression spring tightly together against the restoring force of the spring. These compressed springs are then inserted into apertures of an interposer-layer 24 which is disposed between two printed circuit boards (10, 12). The assembly (board, interposer with precompressed springs, board) is the heated such that the solder holding the coils of the springs again liquifies and releases the spring tension. The springs are therefore permitted to expand and to establish contact between the abutting printed circuit levels (boards).

U.S. Patent No. 4,667,219 (Lee, et al.; 5/87; USCL 357/68), entitled SEMICONDUCTOR CHIP INTERFACE, discloses a connector plate (80) having a plurality of apertures (82) disposed beneath a semiconductor chip (18) having an array of contacts (44,46,48). The apertures of the plate are aligned with the contacts of the chip. A plurality of flexible conductors (described as S-shaped copper wires 84 in Figure 8) extend through the respective apertures of the connector plate to connect (e.g., be soldered) to the chip contacts and terminals (transmission elements 64,67,72) disposed below the connector plate. Thus, each contact on the chip is flexibly and electrically coupled to a respective one of the terminals.

U.S. Patent No. 4,705,205 (Allen, et al.; 11/87; USCL 228/180), entitled CHIP CARRIER MOUNTING DEVICE describes an "interconnection preform placement device" (also known as an "interposer"). In Figures 11A-11C, 12 and 13 of the patent there are described a variety of solder "preforms" which have S-shapes (Figures 11A, 11B, 11C) or C-shapes (Figure 12), or a coiled spring configuration (Figure 13). The preforms are disposed in apertures (holes) through support ("holder", "retaining") layers (e.g., 50 and 52 in Figure 11A). The C-

shaped preform is disposed around the edge of a support layer. The preforms are a "filled solder composition" (a solder material which contains a filler of discrete particles or filaments) or a "supported solder" (solder supported by a support strand or tape which is disposed about the outside of the solder preform shape), which will retain its shape upon the solder melting or reflowing. For example, the particles in a filled solder composition should have a melting point above the melting point of the solder. Filler materials such as copper, nickel, iron, and metal-coated high-temperature polymer or glass films are disclosed and, as mentioned, can be in the form of discrete particles (e.g., powders) or continuous lengths with a single strand or many strands in each preform.

As mentioned hereinabove, electronic components are often connected to printed circuit boards (PCBs), also known as printed wiring boards (PWBs). Printed circuit board (PCB) technology is well developed, and generally involves forming conductive traces on an insulating substrate to effect often complex interconnections between electronic components mounted to or plugged into the PCB. PCBs having conductive traces on both sides of the board are known, as well as multi-layer arrangements of alternating insulating and conductive layers. Additionally, effecting connections from layer-to-layer, within the PCB, are generally well known. A more comprehensive discussion of basic PCB technology can be found in Printed Circuits in Space Technology, Linden, Prentice-Hall Inc., 1962, incorporated by reference herein. It should clearly be understood that, in any of the embodiments described hereinbelow setting forth PCB substrates, these substrates can be formed of materials other than "traditional" printed circuit board materials. For example, the "PCB" substrate can be formed of one or more layers of plastic material, such as polyimide, optionally with conductive foil layers sandwiched therebetween, as is known. The term "circuitized" will also appear

hereinbelow, and refers to the conductive patterns, and the like, present on PCB substrates.

U.S. Patent No.4,532,152 (Elarde; 7/85; USCL 427/96), entitled FABRICATION OF A PRINTED CIRCUIT BOARD WITH METAL-FILED CHANNELS, discloses a plastic substrate which is injection molded to provide a pattern of channels in at least on of its sides to define a predetermined set of conductive paths. Metallizing the substrate by flame spraying, electroless plating, electroplating, gas plating or vacuum deposition is disclosed. The substrate (e.g., 20 in Figure 12) may be provided with plated through holes (58) permitting electronic components mounted on one side of the printed circuit board to be electrically interconnected to conductive paths on the other side of the printed circuit board. This patent is cited simply as being illustrative of plated through holes.

Generally, each of the aforementioned techniques for effecting electrical connections between electronic components requires its own "methodology" - in other words, each requires its own distinct type (e.g., bond wires, pins, etc.) of connection structure.

Moreover, each of the aforementioned techniques suffers from inherent limitations. For example, replacing a first electronic component that is permanently connected to a second electronic component typically requires carefully un-soldering the first electronic component from the second electronic component, then carefully soldering a replacement first electronic component to the second electronic component. Sockets address this concern, but add (often unacceptable) cost to the overall system. Moreover, socketing tends to exhibit inferior connection reliability, as contrasted with soldered connections. Surface mount techniques, such as the aforementioned technique of providing the first electronic

component with solder balls and providing the second electronic component with conductive pads require carefully controlled processes to effect reliably, and do not lend themselves well to disassembly (replacement of one of the electronic components).

Returning to the popularity of using gold to make connections between electronic components, although gold exhibits excellent electrical conductivity, it suffers from certain shortcomings, as relevant to the present invention. For example, gold has a very low yield strength, a characteristic which makes it extremely counter-intuitive to employ a gold wire in (or as) a resilient contact structure. Simply stated, when physically stressed, gold (e.g., a gold wire) will tend to deform, and to retain its deformed configuration. This is called "plastic deformation".

Another shortcoming of using gold wires as an interconnect medium is gold's propensity to react with solder - namely with the tin content of common lead-tin solder. Notwithstanding this fact, certain "eutectic" materials are known, such as gold-tin, which tend to exhibit desireable interconnection properties. Eutectic materials and their properties are discussed in greater detail hereinbelow.

DISCLOSURE (SUMMARY) OF THE INVENTION

It is a general object of the present invention to provide improved techniques for interconnecting electronic components, especially microelectronic components.

It is another object of the present invention to provide improved techniques for mounting contact structures to electronic components, especially semiconductor dies.

It is another object of the present invention to provide improved techniques for fabricating resilient contact structures.

It is another object of the present invention to provide improved techniques for making electronic assemblies.

It is another object of the present invention to provide improved techniques for making wire bond connections to electronic components, including improvements in severing bond wires.

It is another object of the present invention to provide improved techniques for plating objects.

According to the invention, a flexible elongate member (such as a gold wire) is mounted to a contact area (such as a terminal or a pad) on a surface of an electronic component (such as a semiconductor die, a printed circuit board or a semiconductor package) and is configured to have a springable shape (such as a "**wire stem**" having at least one bend).

The elongate member functions as a "**falsework**" for a subsequent "**superstructure**" (overcoat) which is fabricated over the falsework. The superstructure includes at least one layer

applied, such as by plating, over the falsework (or, over previously applied superstructure layers), and covers not only the falsework, but also a remaining area of the contact area on the substrate. The superstructure (overcoat) is a continuous structure covering the contact area and the wire stem.

A resulting resilient and/or compliant (springy) contact structure is thereby formed which is securely mounted to the electronic component and which may be used for effecting temporary and/or permanent connections of the electronic component to another electronic component, or which may be used to effect permanent (e.g., soldered) connections of the electronic component to another electronic component.

Generally, as used herein, compliance encompasses resilience (elastic deformation) and flexibility (plastic deformation). In some instances, both plastic and elastic deformation are desired. In other instances (such as contact structures used for probes), elastic deformation only is desired, but some plasticity may be acceptable. In other instances, true springs, exhibiting purely elastic deformation, are not desired, as they would impose too high of a load upon the substrate whereupon they are mounted. In other instances (such as contact structures on interposers), pure plasticity may be desired to accommodate non-planarity. The present invention permits tailoring the plastic and elastic deformation of a contact structure to the application (e.g., load conditions) for which it is intended.

According to an aspect of the invention, the stem may serve little purpose once the superstructure has been fabricated - a point which is driven home by the fact that, in certain embodiments of the invention, the stem can be partially or fully removed after fabricating the superstructure, without significantly diminishing the structural or electrical

characteristics of the resulting resilient contact structure. Moreover, as described in greater detail hereinbelow, the stem need not be electrically conductive. Generally, once overcoated, the stem (if not removed) will have little or no structural impact on the mechanical characteristics of the resulting contact structure.

In most of the embodiments of the invention disclosed herein, the stem has a springable shape so that it can function as an "**inchoate**" resilient structure. However, in certain embodiments disclosed herein, the stem is simply formed to be straight - resiliency of the resulting contact structure not being of concern in these certain embodiments.

In an exemplary embodiment of the invention, the falsework (wire stem) is a gold wire having a diameter in the range of 0.0007-0.0020 inches (0.7-2.0 mils), and the superstructure (overcoat) is a nickel plating having a thickness in the range of 0.0001 - 0.0100 inches (0.1 - 10.0 mils).

According to an aspect of the invention, a plurality of resilient contact structures are mounted to an electronic component having a plurality of contact areas. For example, up to hundreds of resilient contact structures can be mounted to a semiconductor die or to a semiconductor package having up to hundreds of bond pads or package pads, respectively.

According to an aspect of the invention, a plurality of resilient contact structures can originate from contact areas at different levels on one or more electronic components, and can be fabricated so that they all terminate at a common plane, for connecting to another electronic component having a planar surface.

According to an aspect of the invention, two or more

resilient contact structures can be fabricated on a single contact area of an electronic component.

According to an aspect of the invention, a first group of resilient contact structures can be fabricated on a first face of an electronic component (such as an interposer substrate), and a second group of resilient contact structures can be fabricated on a second, opposite face of the interposer substrate, for effecting electrical interconnections between two electronic components between which the interposer substrate is disposed.

Alternatively, both groups of resilient contact structures can originate from the same face of the interposer substrate, and one group can extend through openings in the interposer substrate to project from the opposite face of the interposer substrate.

Alternatively, resilient contact structures can be formed in through holes extending through support members, the resilient contact structures extending beyond the opposite surfaces of the support member to contact electronic components disposed against the opposite surfaces of the support member.

According to an aspect of the invention, certain improvements in wirebonding are disclosed, such as providing ultrasonic energy during playing a wire out of a capillary of a wirebonder, and such as providing ultraviolet light during severing the wire by electronic flame off (EFO) techniques.

According to an aspect of the invention, the rigidity (stability) of a "conventional" wire bond (such as a bond wire extending between a bond pad on a semiconductor die and a leadframe finger) can be improved by overcoating the bond wire

with a superstructure. This is important, for example, in avoiding shorting adjacent wires during transfer molding of a package body.

Notwithstanding the many alternate embodiments described herein, generally, a wire is bonded at one end to a terminal, pad, or the like, is configured to have a springable shape, and is severed to be a free-standing wire stem. This is suitably performed with wire-bonding equipment. The wire itself, which may be a conventional gold bond wire, does not function as a spring. The ease with which it is shaped (e.g., into an S-shape) is generally contrary to its ability to function as a spring.

The free-standing wire stem is overcoated (e.g., plated) with a conductive, metallic material that serves two principal purposes:

(a) it is a springy (resilient) material such as nickel, so that the resulting overcoated wire stem (contact structure) can behave as a spring; and

(b) it covers the terminal (or pad, or the like) to firmly anchor the wire stem (and the resilient contact structure) to the terminal.

In most of the embodiments disclosed herein, it is the overcoat material that effects the desired electrical interconnection. However, in certain embodiments, the wire stem is exposed at the tip (distal end) of the contact structure, and effects (or augments) the electrical interconnection.

Various applications for contact structures fabricated according to the techniques of the present invention are described, including mounting the contact structures to semiconductor dies, packages, PCBs, etc. The use of resilient contact structures as probes is also described. Bonding the

wire stem to a sacrificial element (or member, or structure) is also described. Multi-layer coatings over the wire stem are also described.

Numerous additional features and embodiments of the invention are set forth hereinbelow, and it should be understood that certain features described with respect to certain embodiments are not necessarily limited to those certain embodiments.

Advantages of the present invention include, but are not limited to:

(a) resilient and/or compliant contact structures can be mounted directly to semiconductor dies either prior to singulating the dies from a semiconductor wafer or after singulating the dies from a semiconductor wafer;

(b) the resilient contact structures can be used to temporarily connect to the electronic component for procedures such as burn-in and testing of the electronic component, and the same resilient contact structures can be used to permanently connect to the electronic component.

Other objects, features and advantages of the invention will become apparent in light of the following detailed description thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference will now be made in detail to preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. Although the invention will be described in the context of these preferred embodiments, it should be understood that it is not intended to limit the spirit and scope of the invention to these particular embodiments.

Figure 1 is a perspective view of a supply wire having its free (proximal) end bonded to a substrate by a bonding head (capillary) of a wirebonder, according to the prior art.

Figure 1A is a side view of a wire having its free end bonded to a terminal on a substrate, according to the present invention.

Figure 1B is a side view of a wire having its free end bonded to a substrate, through an opening in a photoresist layer, according to the present invention.

Figure 1C is a side view of a wire having its free end bonded to a metal layer applied to a substrate, through an opening in a photoresist layer, according to the present invention.

Figure 1D is a side view of the substrate of **Figure 1C**, with the wire overcoated, according to the present invention.

Figure 1E is a side view of the substrate of **Figure 1D**, with the photoresist layer removed and the metal layer partially removed, according to the present invention.

Figure 1F is a side view of a wire having its free end bonded to substrate, which may be a sacrificial substrate,

according to the prior art.

Figure 2 is a perspective view of a wire, having had its free end bonded to a substrate, and configured into a shape, according to the present invention. This figure also schematically illustrates certain components of a preferred wirebonder (springing machine), according to the present invention.

Figure 2A is a side view of a wire, having had its free end bonded to a substrate, and configured into a shape which will support a resilient overcoat, according to the present invention.

Figure 2B is a side view of a wire, having had its free end bonded to a substrate, and configured into a shape which will support a resilient overcoat, according to the present invention.

Figure 2C is a perspective view of a wire, having had its free end bonded to a substrate, and configured into a shape which will support a resilient overcoat, according to the present invention.

Figure 2D is a side view of a wire, having had its free end bonded to a substrate, and configured into a shape which will support a resilient overcoat, according to the present invention.

Figure 2E is a side view of a wire, having had its free end bonded to a substrate, and configured into a shape which will support a resilient overcoat, according to the present invention.

Figure 2F is a side view of a wire, having had its free

(proximal) end bonded to a substrate, and its opposite (distal) end also bonded to the substrate, in a "loop" embodiment of the present invention, wherein the wire loop can be overcoated with solder, according to the present invention.

Figure 2G is a side view of a wire, having had its free (proximal) end bonded to a substrate, configured into a shape which will support a resilient overcoat, and having its opposite (distal) end also bonded to the substrate, according to the present invention.

Figure 2H is a side view of a wire, having had its free end bonded to a substrate, and configured into a straight, pin-like shape, according to the present invention.

Figure 3A is a schematic illustration of a "problem" associated with configuring a wire into a desired shape, according to the present invention, illustrating that the wire will tend to "lead" or "lag" a trajectory taken by the capillary.

Figure 3B is a schematic illustration of a "solution" to the "problem" set forth in **Figure 3A**, according to the present invention, illustrating that the trajectory of the capillary can advertently be offset (altered) to ensure that the wire is fabricated into its desired shape.

Figure 4A is a side view of a wirebonding head (capillary) elevated above a substrate, with an electrode for performing electronic flame off (EFO) severing of the wire, according to an aspect of the present invention.

Figure 4B is a side view of a wirebonding head (capillary) elevated above a substrate, after the wire has been severed by the technique of **Figure 4A**, according to an aspect of the

present invention.

Figure 4C is a side view of a wirebonding head (capillary) elevated above a substrate, after the wire has been severed by an alternate (to **Figure 4B**) technique, according to an aspect of the present invention.

Figure 4D is a side view of a wirebonding head (capillary) elevated above a substrate, after the wire has been severed by an alternate (to **Figures 4B and 4C**) technique, according to an aspect of the present invention.

Figure 5 is a side view of a wire which has been configured to have a shape, and which has been overcoated with multiple (at least two) layers of material to create a resilient contact structure, according to the present invention.

Figure 5A is a side view of a wire which has been configured to have a "springable" shape (a shape which will determine a configuration), and which has been fully overcoated ("enveloped") with a single layer of material to create a resilient contact structure, according to the present invention.

Figure 5B is a side view of a wire which has been configured to have a springable shape, and which has been partially overcoated ("jacketed") with a single layer of material to create a resilient contact structure, according to the present invention.

Figure 5C is a side view of a wire which has been configured to have a springable shape, and which has been fully overcoated ("enveloped") with a single layer of material to create a resilient contact structure having microprotrusions on its surface, according to the present invention.

Figure 5D is a side view of a wire which has been configured to have a springable shape, and which has been fully overcoated ("enveloped") with multiple (at least two) layer of material to create a resilient contact structure having microprotrusions on its surface, according to the present invention.

Figure 5E is a side view of a wire which has been configured to have a springable shape, and which has been fully overcoated ("enveloped") with a layer of material, and which has further been embedded in a compliant electrically-conducting material, such as an elastomer material, according to the present invention.

Figure 5F is a schematic illustration of an exemplary resilient contact structure configured into a springable shape and overcoated (overcoating omitted from this figure), according to the present invention, showing the ability of the contact structure to deflect in response to an applied deflecting force (F).

Figure 5G is a side view of a wire which has been configured to have a springable shape, and which has been fully overcoated ("enveloped") with at least one coating, in conjunction with applying heat during the overcoat (e.g., plating) process, according to the present invention.

Figure 5H is a side view of a wire which has been configured to have a straight, pin-like shape, and which has been fully overcoated ("enveloped") with at least one coating, in conjunction with applying heat during the overcoat (e.g., plating) process, according to the present invention.

Figure 5I is a side view of an embodiment wherein two wire stems are mounted to a single terminal and overcoated, according

to the present invention.

Figure 6A is side view of an application for the resilient contact structures of the present invention, illustrating that the contact structures can "originate" from various levels on one or more electronic components and can "terminate" at a common, coplanar level.

Figure 6B is side view of an application for the resilient contact structures of the present invention, illustrating that the contact structures can "originate" from a level on an electronic component and can "terminate" at a various levels on one or more electronic components.

Figure 6C is side view of an application for the resilient contact structures of the present invention, illustrating that the contact structures can "originate" from a surface of a first electronic component, and can "terminate" at a surface of a second electronic component, wherein the surface of the second electronic component is not parallel to the surface of the first electronic component.

Figure 7A is a side view of a ceramic semiconductor package which has an array of resilient contact structures disposed in an array on an external surface of the package, according to the present invention.

Figure 7B is a side cross-sectional view, partially in perspective, of a plastic semiconductor package which has an array of resilient contact structures disposed in an array on an external surface of the package, and which also has a plurality of resilient contact structures interconnecting a semiconductor die within the package, according to the present invention.

Figure 7C is a side view of a PCB-based semiconductor package which has an array of resilient contact structures disposed in an array on an external surface of the package, according to the present invention.

Figure 7D is a side view of an overmolded package wherein bond wires have been overcoated to enhance their strength, especially their stability during overmolding, according to the present invention.

Figure 8A is a side view of a wire configured into a loop, with the distal end of the wire bonded to a sacrificial element, according to the present invention.

Figure 8B is a side view of the looped wire of **Figure 8A** after being overcoated, according to the present invention.

Figure 8C is a side view of the looped, overcoated wire of **Figure 8B** after the sacrificial element has been removed, according to the present invention.

Figure 8D is a side view of the looped wire of **Figure 8A** after the sacrificial element has been removed, but before the wire has been overcoated, according to an alternate embodiment of the present invention.

Figure 9A is a side view of a wire configured into a shape and overcoated, in an embodiment of a resilient probe, according to the present invention.

Figure 9B is a side view of a wire configured into a shape and overcoated, in an alternate embodiment of a resilient probe, according to the present invention.

Figure 9C is a side view of a multilayer contact pad for

a resilient contact structure, according to the present invention.

Figures 10A-10C are side views of a first phase (Phase-1) of a process for forming a chip-probing card having resilient contacts, according to the present invention.

Figures 10D-10G are side views of a second phase (Phase-2) of a process for forming a chip-probing card having resilient contacts, according to the present invention.

Figures 10H-10I are side views of an alternate embodiment of a second phase (Phase-2) of a process for forming a chip-probing card having resilient contacts, according to the present invention.

Figure 10J is a side view of an embodiment of a wire configured and overcoated to function as a probe, according to the present invention.

Figure 10K is a side view of another embodiment of a wire configured and overcoated to function as a probe, according to the present invention.

Figures 11A-11F are side views illustrating a process sequence for mounting resilient contact structures to a sacrificial substrate, according to the present invention.

Figures 12A-12C are side views of a "gang transfer" technique for mounting resilient contact structures to an external surface of a semiconductor package, according to the present invention.

Figure 12D is a side view of a technique for mounting resilient contact structures to recesses in a surface of a

semiconductor package, according to the present invention.

Figure 12E is a side view of a technique for making a probe card, according to the present invention.

Figure 12F is a side view of a technique for disposing an outer layer on a resilient contact structure, such as to make it more secure on the substrate to which it is mounted, according to the present invention.

Figure 13A is a side view of a semiconductor package having resilient contact structures and making temporary (e.g., resilient) connection to a test board, such as for test and burn-in, according to the present invention.

Figure 13B is a side view of the semiconductor package of **Figure 13A** making permanent (e.g., soldered) connection to a printed circuit board, according to the present invention.

Figures 14A - 14E are side views of a technique for mounting resilient contact structures to a semiconductor die, according to the present invention.

Figures 14F and 14G are side views of a technique, similar to that described with respect to **Figures 14A-14E**, for mounting resilient contact structures to semiconductor dies prior to their singulation from a wafer, according to the present invention.

Figure 15 is a perspective, partial view of a plurality of resilient contact structures mounted to multiple die sites on a semiconductor wafer, according to the present invention.

Figure 15A is a perspective, partial view of a plurality of resilient contact structures mounted to a semiconductor die,

and increasing the effective pitch of the "pin out" (bond pad spacing, as used herein), according to the present invention.

Figures 16A - 16C are perspective views of a process for forming resilient contact structures on dies (either on a wafer or diced therefrom), according to the present invention.

Figure 16D is a perspective view of an alternate (to **Figures 16A-16C**) process for forming resilient contact structures on dies (either on a wafer or diced therefrom), according to the present invention.

Figures 16E and 16F are side views of a technique for fabricating resilient contact structures in a manner suitable for stacking chips (semiconductor dies), one atop another, according to the present invention.

Figure 17A is a perspective view of an embodiment of an interposer, according to the present invention.

Figure 17B is a perspective view of an embodiment of an interposer, according to the present invention.

Figure 17C is a perspective view of an embodiment of an interposer, according to the present invention.

Figure 17D is a perspective view of an embodiment of an interposer, according to the present invention.

Figure 17E is a side view of an embodiment of an interposer, according to the present invention.

Figure 18A is a side view of an embodiment of an interposer, according to the present invention.

Figure 18B is a side view of the interposer of **Figure 18A** disposed between two electronic components, according to the present invention.

Figure 19A is a side view of another embodiment of an interposer, according to the present invention.

Figure 19B is a side view of the interposer of **Figure 19A** disposed between two electronic components, according to the present invention.

Figure 20A is a side view of another embodiment of an interposer, according to the present invention.

Figure 20B is a side view of the interposer of **Figure 20A** disposed between two electronic components, according to the present invention.

Figure 21 is a perspective view of another embodiment of an interposer, suitable for making engineering changes, according to the present invention.

Figures 22A and 22B are side views of additional embodiments of interposers, according to the present invention.

Figure 22C is a side view of another embodiment of an interposer, according to the present invention.

Figures 22D-22F are side views of another embodiment of an interposer, according to the present invention.

Figure 23A is a side view of an embodiment of a semiconductor package incorporating resilient contact structures mounted thereto, according to the present invention.

Figure 23B is a side view of another embodiment of a semiconductor package incorporating resilient contact structures, according to the present invention.

Figure 23C is a side view of a flip-chip ready, via-less PCB substrate having external contacts, according to the present invention.

Figure 24A is a partial perspective view of an embodiment of a loop-shaped contact formed on a terminal of a substrate, according to the present invention.

Figure 24B is a partial perspective view of an embodiment of a solder bump type contact formed on a terminal of a substrate, according to the present invention.

Figures 24C-24D are partial perspective views of an embodiment of a thermal interconnect formed on a terminal of a substrate, according to the present invention.

Figure 24E is a perspective view of another embodiment for providing an electronic component with thermal-dissipation structures, according to the present invention.

Figure 25 is a side view of an embodiment of an assembly of a double-sided printed circuit board having electronic components mounted with resilient contact structures to both sides thereof, according to the present invention.

Figure 26 is a side view of an embodiment of an assembly of a double-sided printed circuit board having electronic components mounted with resilient contact structures to both sides thereof, according to the present invention.

Figure 27 is a side view of an embodiment of an assembly

of a printed circuit board having an electronic component mounted thereto with resilient contact structures, according to the present invention.

Figure 28 is a side view of an embodiment of an assembly of a printed circuit board having an electronic component mounted thereto with resilient contact structures, according to the present invention.

Figure 29 is a side view of an embodiment of an assembly of a printed circuit board having electronic components mounted thereto with resilient contact structures, according to the present invention.

Figure 30 is a side view of an embodiment of an assembly of a printed circuit board having electronic components mounted thereto with resilient contact structures, according to the present invention.

Figure 31 is a side view of an embodiment of an assembly of a printed circuit board having electronic components mounted thereto with resilient contact structures, and incorporating another electronic device, according to the present invention.

Figure 32 is a side view of an embodiment of an assembly of a printed circuit board having electronic components mounted thereto with resilient contact structures, and incorporating another electronic device, according to the present invention.

Figure 33 is a side view of an embodiment of a packaging scheme for electronic components, according to the present invention.

Figure 34 is a side view of an embodiment of a packaging scheme for electronic components, according to the present

invention.

Figure 35 is a side view of an embodiment of a connection scheme for electronic components, according to the present invention.

Figure 36A is a side view of an embodiment of an assembly of a printed circuit board having electronic components mounted thereto with resilient contact structures, according to the present invention.

Figure 36B is a plan view of an electronic assembly, according to the present invention.

Figure 36C is a plan view of an electronic assembly, according to the present invention.

Figure 37 is a side view of an embodiment of an assembly of a printed circuit board having electronic components mounted thereto with resilient contact structures, and incorporating another electronic device, according to the present invention.

Figure 38 is a side view of an embodiment of an assembly of a printed circuit board having electronic components mounted thereto with resilient contact structures, according to the present invention.

Figure 38A is a detailed side view of the embodiment of **Figure 38**, according to the present invention.

Figure 39 is a side view, partially exploded, of a test interface arrangement, according to the present invention.

Figure 40A is a side view of an embodiment of the invention utilizing an insulating (e.g., dielectric) material for forming

the wire stem, according to the present invention.

Figure 40B is a side view of an embodiment of the invention utilizing an insulating (e.g., dielectric) material for forming the wire stem, according to the present invention.

Figure 41A-41C are side views of an alternate technique for mounting a wire stem to a contact area (e.g., terminal) on an electronic component, according to the present invention.

Figure 42 is a side view of an alternate technique for configuring a wire stem, with an external tool, according to the present invention.

Figures 42A and 42B are side views illustrating a technique for shaping to or more wire stems with an external tool, according to the present invention.

Figure 42C is a perspective view of an alternate technique for shaping a plurality of wire stems with external comb-like tools, according to the present invention.

Figure 43A is a side view of a capillary of a wirebonder, according to the present invention.

Figure 43B is a side view of an alternate embodiment of a capillary of a wirebonder, according to the present invention.

Figure 44 is a plan view of an electronic component to which a plurality of resilient contact structures are mounted, with their orientations arranged to accommodate thermal expansion of the electronic component, according to the present invention.

Figure 45 is a perspective view of a resilient contact

structure mounted to a substrate and accommodating a compressive force (F) in torsion (T), according to the present invention.

Figures 46A-46F are side views, illustrating a technique for reducing overall inductance of a resilient contact structure, according to the present invention.

Figure 46G is a cross-section of an insulated wire of the prior art which may be employed in certain embodiments of the present invention.

Figure 47 is a side view of a wire stem having its thickness (e.g., diameter, for a round wire) modified, according to the present invention.

Figures 48A-48E are side views, partially in cross-section, of a technique for removing the wire stem after overcoating, according to the present invention.

Figures 49A-49C are side views, partially in cross-section, of a technique for forming a eutectic, braze-ready tip on a contact structure, according to the present invention.

Figures 50A and 50B are perspective views of techniques for providing contact structures with topographical (rough) tips, according to the present invention.

Figures 51A-51C are side views, partially in cross-section, of a technique for forming a contact structure with a demi-overcoat, according to the present invention.

Figures 52A-52D are perspective views of a technique for fabricating a resilient contact structure suitable for making interconnection to an exposed, middle portion of the wire stem, according to the present invention.

Figure 52E is a perspective view of a technique for fabricating multiple free-standing contact structures without severing the wire stem, according to the present invention.

Figure 52F is a side view of an alternate technique for fabricating multiple free-standing contact structures without severing the wire stem, according to the present invention.

Figures 53A and 53B are side views of an alternate technique for multiple free-standing contact structures without severing the wire stem, according to the present invention.

Figures 53C and 53D are side views, illustrating a technique for making free-standing wire stems, without electronic flame off, in this case, from loops, according to the present invention.

Figure 54 is a side view, showing a portion of a contact structure interconnecting to an external component, according to the present invention.

In the side views presented herein, often portions of the side view are presented in cross-section, for illustrative clarity. For example, in many of the views, the wire stem is shown full, as a bold line, while the overcoat is shown in true cross-section (often without crosshatching).

In the figures presented herein, the size of certain elements are often exaggerated (not to scale, vis-a-vis other elements in the figure), for illustrative clarity.

In the figures presented herein, elements are often numbered with the Figure number as a "prefix", and the "suffixes" often refer to similar elements (e.g., element 108

of **Figure 1** is a substrate, as is element 208 of **Figure 2**, as is element 808 in **Figure 8A**).

DETAILED DESCRIPTION OF THE INVENTION

The aforementioned CASE-1, incorporated by reference herein, discloses a method for manufacturing raised (protuberant), resilient electrical contacts of precise shape and geometry on a wide variety of electronic components, said contacts having a controlled set of physical, metallurgical and mechanical properties, bulk and surface, to satisfy electrical, thermal or geometric requirements in various aspects of electronic interconnection applications.

Generally, a multiple step process is described wherein:

(a) wire stems are created on terminals of an electronic component;

(b) the wire stems are shaped in three-dimensional space to define skeletons of resulting contact structures;

(c) the wire stems are coated in at least one deposition step with a coating which envelops or jackets (partially envelops) the skeletons and the terminals. The common coating not only helps to "anchor" the protruding contact structures to the terminals, but also:

(1) provides for characteristics of the protuberant contacts with respect to long term stability of their engagement contact with mating electronic components;

(2) determines soldering assembly characteristics, as well as long term effects from contact with solder; and

(3) determines the mechanical characteristics of the resulting protuberant contact structure.

Generally, the wire serves as a "skeleton" of a resulting protruding contact (i.e., as a "proto" resilient contact), and the coating serves as its "muscle". In other words, the wire (which is shaped) defines a shape for the resulting contact, and the coating over the wire imparts the sought-after resilient (and conductive) properties to the contact. In this regard, the

coating is considered to be a principal structural element of the contact, and to this end has a predetermined combination of thickness, yield strength and elastic modulus to ensure predetermined force-to-deflection characteristics of the resulting spring contacts. An important feature of the coating is that it is continuous. Employing a plurality of (such as two) wire stems to create a skeleton for a resilient contact is also discussed.

CASE-1 discloses mounting the resilient contact structures to a variety of electronic components, including:

(a) ceramic and plastic semiconductor packages;

(b) laminated printed circuit boards (PCBs), Teflon (tm) based circuit boards, multi-layer ceramic substrates, silicon-based substrates, varieties of hybrid substrates, and other substrates for integration of electronic systems known to those skilled in the art.

(c) semiconductor devices, such as silicon and gallium arsenide devices; and

(d) passive devices, such as resistors and capacitors.

CASE-1 discloses the following wire materials and dimensions:

(a) gold, aluminum or copper, alloyed (or doped) with beryllium, cadmium, silicon or magnesium;

(b) solder, specifically lead-tin solder wire;

(c) alloys of silver and platinum; and

(d) diameters ranging between 0.0005 and 0.0050 inches.

CASE-1 discloses employing the following wirebonders and techniques:

(a) ball-and-wedge;

(b) wedge-wedge;

(c) application of pressure, temperature or ultrasonic energy, or combinations thereof to form bonds;

(d) controlling the motion of the capillary to set the shape of the wire stem;

(e) programming the software of the control system of the wirebonder to exclude the common wedge bonding step for severing the wires. Instead, the same electronic or hydrogen flame-off used for ball formation prior to the ball bonding is employed to sever the wires at a predetermined height; and

(f) after the capillary moves up to a predetermined position, an electronic flame off (EFO) electrode is brought under high potential, resulting in generation of a spark which melts and severs the wire stem, and readies the feed end of the wire (from the supply spool) for the next stem bonding step.

According to the invention, any suitable means for severing the wire stem can be employed, including:

(a) Electronic Flame Off (EFO);

(b) mechanical means, such as a knife;

(c) laser; and

(d) Hydrogen torch.

CASE-1 discloses depositing tin as a first layer on a gold wire stem, with a subsequent reaction of gold and tin at a temperature below the melting temperature of gold-tin eutectic. A gold-tin alloy results, which is significantly stronger than (pure) gold.

CASE-1 discloses the following coating materials and dimensions:

(a) nickel, copper, cobalt, iron, and their alloys;

(b) noble or semi-noble metals or alloys, selected from a group consisting of gold, silver, rhodium, ruthenium and copper, and elements of the platinum group and their alloys;

(c) rhodium, ruthenium, or other elements of the platinum group, and their alloys with gold, silver and copper;

(d) tungsten;

(e) thicknesses between 0.00003 and 0.00700 inches;

According to the invention, palladium is also a suitable coating material.

CASE-1 discloses the following coating processes:

(a) wet electrochemical, e.g., through electrolytic or electroless aqueous solution plating of metals of the skeleton and on the terminal;

(b) electroplating of nickel out of nickel and its alloys (tensile strength in excess of 80,000 pounds per square inch);

(c) wave solder, or electrolytically deposited solder;

(d) physical (PVD) and chemical (CVD) vapor deposition methods, and also the deposition of conductive coatings through various decomposition processes of gaseous liquid or solid precursors.

CASE-1 discloses applying multi-layer coatings over a wire stem. For example:

(a) overcoating nickel (which has a strong tendency to oxidize) with a noble or semi-noble coating layer such as gold, silver, elements of the platinum group, and their alloys.

(b) selecting the multiple layers of the coating to tailor the properties of the protuberant contact to a given application.

CASE-1 discloses that the wire stem (skeleton) can be overcoated with a spring coating having local protrusions. Such a coating can be created through dendritic growth of an electroplated deposit, or through incorporation of foreign particulates into the conductive deposit. Alternatively, a regular uniform first deposit layer can be applied, which provides for resilient properties, and the subsequently deposited top layer incorporates local protrusions or particulates to complete the conductive overcoat. The local

protrusions dramatically increase the local pressures exerted by the resilient protruding contact onto a mating terminal during the interconnection engagement, and reduce contact resistance when contacting easily passivating, oxide-forming materials overlying the engaged terminals.

CASE-1 discloses that improvement in the mechanical strength of the resulting contact can be achieved when a coating with a compressive internal stress is deposited, which effectively increases the stress level required to deform or break a resulting protuberant electrical contact. The compressive internal stress in the coating improves the spring characteristics of the resulting contact, as well as providing control over its strength and ductility levels.

CASE-1 discloses achieving coplanarity, in the context of:

(a) the uppermost points (distal ends) of the contacts can be made to extend to a vertical (above the surface of the electronic component) coordinate which is substantially identical (for all of the contacts on the electronic component).

(b) the contacts can originate from two or more electronic components, and their distal ends can be coplanar (all having the same vertical coordinate), for subsequent contact to another, planar, electronic component;

(c) the contacts can originate from different levels of an electronic component, and their distal ends can be made coplanar; and

(d) the vertical coordinates of the tips (distal ends) of the contacts is readily controlled by a software algorithm implemented in the control system of a wirebonder.

CASE-1 discloses that the wire stem can span between a terminal and a sacrificial layer, said sacrificial layer being temporarily used for processes such as electroplating of the wire stem.

CASE-1 discloses that columns of solder having controlled (e.g., high) aspect ratios and shapes can be formed. In this context, the application of a barrier layer of 100-1000 microinch thick nickel alloy between the wire stem (especially gold) and the solder overcoat (especially lead-tin alloys, such as near-eutectic lead-tin) is described. Such solder columns are protuberant, but are not resilient. The use of multiple (e.g., two) wire stems per solder column is described as advantageous in causing bridging of the solder as opposed wetting only (with one wire stem).

CASE-1 discloses that "loops" can be formed by bonding both ends of the wire stem to a common terminal, and the loops can be employed as the skeletons of solder columns.

CASE-1 discloses that the suspension of the contact (such as by using a sacrificial arrangement) results in formation of controlled geometry spring contacts capable of resiliently engaging with mating terminals on a component or a substrate for testing, burn-in, or demountable electrical interconnect in service.

CASE-1 discloses that the contacts can be used as "replacements" for standard techniques for attaching pins to plastic and ceramic packages. This usefulness is due to the fact that pin-shaped contacts produced by the methods of the invention do not require pattern-specific tooling or molds.

CASE-1 discloses that a skeleton can be formed as a sequence of loop shapes, as a fence bounding a terminal, then filling in the bounded area with solder. Although not resilient, this provides a massive solder pad on the electronic component for thermal interconnection to heat sinks or substrates.

The invention described in CASE-1 is a dramatic departure from the prior art teachings of bond wires that are overcoated, in that:

(a) typically, such prior art overcoats are non-conductive and/or are targeted at providing protection from corrosion; and

(b) the resilient contacts of the present invention advantageously combine the steps of shaping a skeleton (which may be inherently non-resilient, and which may in fact be non-conductive), then overcoating the skeleton with a spring coating (the outer layer of which must be conductive) to obtain a spring (resilient) contact structure.

Among the advantages of the resilient contact structure disclosed in CASE-1 are:

(a) the same contact structure can be used for demountable or permanent attachment of the electronic component.

(b) the spring (resilient) contacts can be used as a standard means of interconnect between substrates and components which have matching patterns of terminals, and can be used on an interposer structure for interconnecting two (or more) electronic components.

The aforementioned CASE-2, incorporated by reference herein, discloses contact structures for interconnections, interposers, and semiconductor assemblies, and methods for making same. Generally, the disclosure of this case "leverages" off the disclosure of CASE-1, insofar as the ability to make resilient contact structures is concerned.

CASE-2 discloses a number of specific uses for resilient contact structures are described, including a variety of interposer embodiments, wherein:

(a) a resilient contact structure is mounted to one side

of an interposer substrate at a plated through hole, and a resilient contact structure is mounted to another, opposite side of the interposer substrate at the plated through hole;

(b) a resilient contact structure is mounted to one side of an interposer substrate at a plated through hole, and looped contact structure is mounted to another, opposite side of the interposer substrate at the plated through hole;

(c) a resilient contact structure having a portion extends from a plated through hole up from one side of the interposer substrate, and having another portion which extends through the through hole to beneath the interposer substrate;

(d) a molded plastic interposer substrate is provided with one set of holes extending into the substrate from one side thereof and another set of holes extending into the substrate from an opposite side thereof. Each pair of holes are offset slightly from one another (eccentric). The holes are plated with a conductive material. Because of the offset, each hole has a shoulder (at its bottom) from which a compliant contact structure can be formed. In this manner, a first set of contact structures extend out of one side of the interposer substrate, and another set of contact structures extend out of an other side of the interposer substrate, and the contact structures are electrically connected to one another by respective through hole plating.

CASE-2 discloses forming a contact structure comprising a plurality (three) skeleton structures spaces on a single contact pad and overcoated with solder, to form a solder post.

CASE-2 discloses forming a composite contact structure wherein a plurality (two or three) resilient contact structures are mounted on a single pad, and further describes securing the ends of the plurality of contact structures together with solder.

CASE-2 discloses forming a contact structure that can serve as a probe, and further describes a probing contact which includes a layer of dielectric material over which is disposed a metal layer to provide a shielded contact with controlled impedance.

CASE-2 discloses forming a contact pad at the free end of a probe contact structure, wherein the contact pad is provided with a plurality of sharp points, and wherein the free end of the probe contact structure is provided with a probe-like tip.

CASE-2 discloses disposing resilient contact structures on a semiconductor device (electronic component), with the tips of the contact structures aligned in two rows, with the uppermost tips of alternate contact structures in each row being offset from the uppermost tips of the other contact structure to provide a staggered arrangement making possible three dimensional fan outs.

CASE-2 discloses disposing contact structures having different configurations, with some having larger bends and other having smaller bends, on an electronic component. CASE-2 further describes staggering the orientation of each "type" contact structure in opposite directions. The utility of such a configuration for performing burn-in and testing of a semiconductor device, by yieldably engaging matching contact pads on a burn-in test substrate is discussed. The use of registration or alignment pins is also discussed. The possibility of having a fine pitch on the contact pads of the semiconductor device upon which the contact structures are mounted, and a coarser pitch for the tips of the contact structures is discussed.

CASE-2 discloses a number of semiconductor package assemblies, wherein resilient contact structures are mounted on

one or two semiconductor devices which, in the case of two semiconductor devices, are provided on both opposite sides of a printed circuit board. The use of resilient contact structures as spring clips to secure the semiconductor device(s) to the printed circuit board is discussed. Forming resilient contact structures to insert snugly (and removably) within plated through holes is discussed. The use of alignment pins is also discussed, with respect to semiconductor package assemblies.

CASE-2 discloses incorporating an additional component, such as a capacitor in a large plated through hole of a printed circuit board, in a semiconductor package assembly.

CASE-2 discloses mounting additional components, such as capacitors, to a printed circuit board, in a semiconductor package assembly.

CASE-2 discloses a number of additional assemblies, employing the resilient contact structure.

In the description that follows, there will (inevitably) be some overlap with the disclosures of CASE-1 and of CASE-2, for the purpose of providing a complete disclosure herein. In the sections immediately following, there is a discussion of the steps of bonding a wire to a substrate, configuring the wire to have a "**springable**" (suitable to act as a spring, when overcoated with a spring material) shape, severing the wire to become a wire stem, and overcoating the wire to form a resilient contact structure which is well anchored to the substrate.

BONDING A WIRE TO AN AREA ON A SUBSTRATE

Figure 1, similar to Figure 1 of CASE-1, shows a wire 102 feeding through a capillary 104 (shown in cross-section) of a wirebonder (not shown in this figure, see **Figure 2** for an illustration of a complete wirebonder). The wire 102 is fed to the capillary from a spool 106. The capillary 104 is brought towards a surface 108a of a substrate 108, so that the free end 102a of the wire 102 contacts the surface 108a of the substrate 108 and is bonded in any suitable manner thereto. Bonding a free end of a wire to a surface of a substrate is well known, and requires no further elaboration.

As shown in **Figure 1**, the free end 102a of the wire 102 is bonded to the surface 108a of the substrate within an arbitrarily defined "**contact area**" 110 (shown in dashed lines). This contact area 110 may be of any shape (rectangular shown, can be circular or any other arbitrary shape), and is notably larger than and encompasses (subsumes) the location (relatively small area) whereat the free, bonded end 102a of the wire 102 is bonded to the surface 108a of the substrate 108.

As will be discussed in greater detail hereinbelow, the bonded end 102a of the wire 102 will, in many embodiments that follow, become the "**proximal end**" of a resulting "**wire stem**".

Figure 1A shows that the free end 102a of the wire 102 may be bonded to a conductive terminal 112 on the surface 108a of the substrate 108. The formation of a conductive terminal (or "pad", or "bond pad") on a surface of a substrate, and bonding a wire thereto is well known. In this case, the terminal 112 constitutes (defines) the contact area 110 (see **Figure 1**). In **Figure 1A**, the capillary 104 is shown in dashed lines, and is stylized.

Figure 1B shows that the free end 102a of the wire 102 may be bonded to a metal (conductive) layer 114 on a (typically non-conductive, or semiconductive) substrate 108, through an opening 116 etched in an overlying layer of photoresist 118. In this case, the opening 116 in the photoresist constitutes the contact area 110 (see **Figure 1**). In **Figure 1B**, the capillary 104 is shown in dashed lines, and is stylized.

Figures 1C, 1D and 1E show a technique for bonding the free end 102a of the wire 102 to a surface of a substrate 108, which is a preferred technique for bonding the wire 102 to semiconductor substrates (see, **Figures 25**, et seq.). In **Figure 1C**, the capillary 104 is shown in dashed lines, and is stylized. In **Figure 1C** it is shown that the conductive layer 120 is (as in **Figure 1B**) disposed on the top surface of the substrate 108. This layer 120 may be a top metal layer, which is normally intended for bond-out to the die, as defined by openings 122 in a passivation layer 124 (typically nitride). In this manner, a bond pad would be defined which would have an area corresponding to the area of the opening 122 in the passivation layer 124. Normally (i.e., according to the prior art), a wire would be bonded to the bond pad.

According to the invention, a blanket layer 126 of metal material (e.g., aluminum) is deposited over the passivation layer 124 in a manner that the conductive layer 126 conformally follows the topography of the layer 124, including "dipping" into the opening 122 and electrically contacting the layer 120. A patterned layer 128 of photoresist is applied over the layer 126 with openings 132 aligned over the openings 122 in the passivation layer 124. An important feature of this technique is that the opening 132 is larger than the opening 122. As will be evident, this will result in a larger bond area (defined by the opening 132) than is otherwise (as defined by the opening 122) present on the semiconductor die (108). The free end 102a

of the wire 102 is bonded to the top (as viewed) surface of the conductive layer 126, within the opening 132. After the wire is configured to have a shape (as described hereinbelow with respect to **Figures 2, 2A-2H**) and is severed (as described hereinbelow with respect to **Figures 4A-4D**) to create a "wire stem", the wire stem is overcoated (as described hereinbelow with respect to **Figures 5, 5A-5F**). (For purposes of this discussion, an overcoated wire stem is a termed a "resilient contact structure" 130.) This is shown, in a general exemplary manner, in **Figure 1D**, wherein it can be seen that a material 134 overcoating the wire stem (i.e., the shaped wire 102 which is shown in **Figures 1D and 1E** as a thick solid line) completely envelops the wire stem and also covers the conductive layer 126 within the area defined by the opening 132 in the photoresist 128. The photoresist 128 is then removed (such as by chemical etching, or washing), and the substrate is subjected to selective etching (e.g., chemical etching) to remove all of the material from the conductive layer 126 except that portion of the layer 126 which is covered by the material 134 overcoating the wire stem. This results in the structure shown in **Figure 1E**, a significant advantage of which is that the contact structure 130 is securely anchored (by the coating material 134) to an area (which was defined by the opening 132 in the photoresist) which can easily be made to be larger than what would otherwise (e.g., in the prior art) be considered to be the contact area of a bond pad (i.e., the opening 122 in the passivation layer 124). In this case, the area defined by the opening 132 in the photoresist 128 is the contact area (110).

Figure 1F shows that the free end 102a of the wire 102 may be bonded to a conductive (e.g., metallic, as indicated by single line cross-hatching) substrate 108 which, as will be discussed in greater detail hereinafter, may be a sacrificial substrate (e.g., a substrate that is dissolved away after bonding the wire thereto). In this case, the contact area 110

is not shown, but is arbitrarily defined in the manner indicated in **Figure 1**. In **Figure 1F**, the capillary 104 is shown in dashed lines, and is stylized.

In all of the cases set forth above (**Figures 1, 1A, 1B, 1C-1E, 1F**), which cases are intended to be exemplary and not limiting, the free end (102a) of the wire (102) is bonded within a defined area (110) on a substrate. However, as is readily apparent from the drawings, the bond (of the proximal end of the wire) itself occupies a relatively small area within the defined area (110). By way of example, the small area of the bond itself may be only 5-50% of the overall area of the contact area 110, and is preferably not at an edge of the contact area, but is preferably more-or-less centered within the contact area.

As is discussed hereinbelow, the wire stem will be overcoated with a material that imparts resiliency thereto, and that anchors itself to the entire contact area.

PROPERTIES OF THE WIRE

The wire is an elongate element of a size and of a material that is easily fabricated into a shape (i.e., "**flexible**"), as discussed hereinbelow. As will become evident, it is not of particular importance to the present invention that wire is capable of conducting electricity between two electronic components since, the wire will (in most of the embodiments described hereinbelow) be entirely overcoated with a conductive material. However, it is certainly within the scope of this invention that the wire is made of a material that is conductive.

Generally, according to the present invention, the "existential" properties of the wire (i.e., its ability to be shaped and overcoated) tend to overshadow its structural or electrical properties. Moreover, once the wire stem is overcoated with a resilient, electrically-conductive material, the wire stem becomes largely superfluous.

An exemplary material for the wire is gold, in the form of a round (cross-section) wire, having a diameter (thickness) of approximately 0.0010 inches (1 mil). This includes, but is not limited to diameters in the range of 0.7 - 2.0 mils. The wire is preferably in the range of 0.0005 to 0.0030 inches (½-3 mils). Such a wire will be very formable (into a desired shape), is an excellent electrical conductor, is very available, and exhibits good long term resistance to corrosion.

Gold wire is readily available from several suppliers, n a variety of sizes (e.g., 0.001 inch diameter) and compositions. For example:

- 99.99% gold, plus beryllium;
- 99.99% gold, plus copper;
- 1% silicon aluminum alloy; and

- 1% magnesium aluminum alloy.

Copper wire, preferably as pure as possible, is also readily available and suitable for use as the wire stem of the present invention.

Other (than gold) suitable materials for the wire, for which a similar range of diameters would be applicable, include:

aluminum;

copper alloyed with small amounts of other metals to obtain desired physical properties, such as with beryllium, cadmium, silicon and magnesium;

gold, copper or aluminum alloyed with materials such as lead, tin, indium, cadmium, antimony, bismuth, beryllium and magnesium;

silver, palladium, platinum;

metals or alloys such as metals of the platinum group; and

lead, tin, indium and their alloys.

Generally, a wire of any material that is amenable to bonding (using temperature, pressure and/or ultrasonic energy to effect the bonding) would be suitable for practicing the invention.

Preferably, the material of the wire is gold, aluminum, copper, or their alloys. For example:

1. Gold, doped (alloyed) with Beryllium (e.g., less than 12 ppm, preferably 5-7 ppm) or Cadmium
2. Aluminum doped with Silicon or Magnesium, alternatively with Silver or Copper
3. Platinum/Palladium mixed with Copper/Silver

As will be discussed in greater detail hereinbelow, in many of the embodiments described herein, the wire is severed to have a distal end and a length. The wire may have any desired

length, but typically would have a length commensurate with its use in conjunction with small geometry semiconductor devices and packages, wherein its length would be: 0.010 inches to 0.500 inches. The wire need not have a circular cross-section, although such is preferred. The wire may have a rectangular cross-section, or may have a cross-section of yet another shape.

As discussed in greater detail hereinbelow (see **Figures 51A and 51B**), the wire stem can be formed of a non-metallic material, such as plastic, and can be overcoated to result in a resilient contact structure.

Traditional wirebonding requires robust bonds to be made at both ends of a wirebond loop to avoid, inter alia, de-cohesion. Bond strength is of paramount importance, and process constraints are relatively very rigid.

According to the present invention, the constraints for bonding a wire stem to a substrate are greatly relaxed (e.g., vis-a-vis traditional wirebonding). Generally, so long as the wire stem stays in place during shaping and overcoating, the bond strength is "sufficient". This also accounts for the wide variety of wire materials set forth hereinabove, the material generally being chosen for properties other than the robustness of a bond formed therewith.

FORMING AND SHAPING OF THE WIRE STEM

Once the free (proximal) end (102a) of the wire (102) has been bonded to the substrate (108), the capillary (104) is moved generally upward (in a z-axis direction) from the surface of the substrate and the substrate, which typically is mounted to an x-y table (not shown) is moved in the x- and y-directions. This imparts a relative motion between the capillary and the substrate which, in the main hereinafter, is described as the capillary being moved in three axes (x-axis, y-axis, z-axis). As the capillary moves, the wire "plays out" of the end of the capillary.

According to the invention, the relative motion between the capillary and the substrate is controlled, and imparts a desired shape to the wire.

In typical wirebonding operations, a free end of a wire is bonded (e.g., to a bond pad on a semiconductor die), the capillary moves up (to a prescribed height above the surface of the substrate), the substrate moves over (typically it is the substrate that is moved to impart relative motion in the x-y plane between the substrate and the capillary), and the capillary is moved back down (e.g., onto a bonding location on conductive traces of a leadframe, a semiconductor package, or the like). The wire plays out of the capillary during this relative movement of the capillary. Although this (e.g., up/over/down) movement of the capillary (in the prior art) imparts a generally arcuate "shape" to the wire (even a straight wire can be considered to have a "shape"), the "shaping" of the present invention is quite different.

As will be quite evident, the wire stem is shaped so that a contact structure comprising a wire stem that is overcoated, such as by plating, functions as a resilient contact structure.

With this in mind, it is evident that the concept of "shaping" the wire, according to the present invention, is entirely different from any incidental (i.e., not intended to establish a resulting resilient contact structure) "shaping" of the prior art. As used herein, the concept of "shaping" the wire differs dramatically from the shaping of the prior art in the manner in which the wire is shaped, both in the underlying purpose of shaping the wire, and in the resulting geometry of the wire shape.

As will be discussed in greater detail hereinbelow, once the proximal end of the wire is bonded to the substrate, it is advertently (versus incidentally) "formed", "fashioned", or configured to have a definite, desirable geometric form which will serve as a what has been referred to in the parent cases as a "skeleton" for establishing the physical configuration of a subsequent coating over the wire which will conform to the shape of the wire and which will impart resiliency to a subsequent contact structure of the coated wire (other advantages of the coating, in addition to imparting resiliency to the shaped wire stem, are described hereinbelow). Hence, when the terms "configuring", "fashioning", "forming", "shaping" and the like, as used herein, they are specifically intended to be interpreted as having a meaning which describes the ability of the wire to establish a resulting configuration for a coating which will impart resiliency (springiness) to the resulting contact structure (coated wire).

Upon reading this patent application, one having ordinary skill in the art to which the present invention most nearly pertains will understand that once shaped and overcoated, the wire stem itself is essentially superfluous - the overcoat material providing the requisite electrical conductivity and desired mechanical characteristic of the resulting resilient contact structure. However, as will be evident, in certain

embodiments of the invention, it is required that the wire stem is electrically conductive, since electrical contact will be made thereto.

In a sense, the wire stem of the present invention functions in a manner analogous to a "**falsework**" - a temporary scaffolding or support used in construction to establish the resulting shape of stone or brick arches. As a corollary to this analogy, the overcoat can be considered to function as a "**superstructure**".

In another sense, the wire stem functions in a manner analogous to a "**mandrel**" - a **core** around which other materials may be shaped.

In yet another sense, the wire stem functions as a "**template**" - a pattern or model for an item being made or synthesized.

It is understood that these analogies are not perfect, in that falseworks, mandrels and templates are typically removed after serving their intended purpose. In the case of the wire stem of the present invention, it is not necessary to remove the wire stem it is overcoated, although embodiments wherein the wire stem is removed are disclosed.

Perhaps a more apt analogy is that the wire stem serves as an "**outline**", in the manner that an outline can be created prior to writing a book. The outline describes what the book is "going to be", and may be included in the book, or it can be discarded after the book is written. In either case, the outline establishes the resulting form of the book.

In the parent cases, the shaped wire stem was referred to as a "**skeleton**" - a supporting structure or framework. This too

is a useful choice of terms, in that a skeleton typically remains in place. Like the human skeleton (framework of bones) which determines the shape of the overlying tissue, the wire stem of the present invention establishes the shape of the resulting contact structure. However, unlike the human skeleton which must remain in place in order for the overlying tissue to perform its intended function, and which contributes significantly to the "mechanical" characteristics of the human body, the wire stem of the present invention need not remain in place in order for the overlying material coating to perform its intended function, and the wire stem does not contribute significantly to the mechanical characteristics of the resulting contact structure.

One of the significant advantages of using a readily-deformable, malleable, compliant material for the wire stem is that it is readily configured to establish a shape for the overcoat applied thereto, without significantly altering the physical properties (e.g., tensile strength, resiliency, etc.) of the resulting resilient contact structure. Inasmuch as the wire stem serves as an important first step in the overall process (begun, but not completed) of fabricating a resulting contact structure, the wire stem can be characterized as an "**inchoate**" contact structure.

Since the present invention is primarily targeted at fabricating resilient contact structures for interconnecting electronic components such as semiconductor dies, said resilient contact structures, in many cases, being barely visible to the naked eye, the contribution and configuration of the wire stem can more easily be visualized by taking a length (e.g., a six inch length) of malleable wire (such as 14 gauge copper wire, or comparable gauge lead-tin solder wire), mounting a one end of the wire in a hole in a wooden block, and manually (by hand) shaping a free-standing wire stem having any of the springable

configurations described herein (e.g., those of **Figures 2A, 2B or 2E**). It will be seen that a compressive force (e.g., of several ounces, applied by the user's fingertip) applied at the tip of the wire stem, towards the block, will result in the wire stem deforming - there being very little "springiness" to the wire stem itself. An analogy to an overcoated wire stem formed according to the present invention would be more like a steel wire (such as a six inch length of coat hanger wire) shaped in the same manner as the solder, in which case the steel wire will exhibit noticeable springiness (or springback) when a compressive force is applied thereto. (It is understood that the steel wire is not an "overcoat" over a deformable wire stem.) The overcoat (e.g., of nickel) on an easily shaped wire stem (e.g., of gold) will exhibit resiliency analogous to that of the coat hanger wire.

In other words, whereas prior art wirebonding, involving bonding an end of a wire at a location, moving (up and over, then down) to another location, then bonding and severing could be considered as imparting a "shape" to the resulting wire, the (generally arcuate) resulting shape is relatively incidental. In contrast to this, according to the present invention, the wire is advertently (rather than incidentally) "**fashioned**", or "**configured**", essentially all along its length to have a particular functional (proto-spring) shape. Another useful terminology for describing imparting a to-be-resilient (when overcoated) shape to the wire is "**convoluting**" (or "configuring") the wire into a "convoluted" shape (or "configuration").

The general inability of a prior art wirebonding loop to function as a resilient contact structure, even if were overcoated (e.g., with nickel) can be demonstrated by inserting both ends of the aforementioned coat hanger wire into two holes in the wooden block, and applying the same compressive force

thereto (at the top of the curve, rather than at the tip). Even with this "crude" model, the loss of springiness can readily be observed.

In many of the embodiments described hereinbelow, a wire is fashioned (configured) to have at least two bends, which also distinguishes the "fashioning" (configuring, shaping, forming) of a shape of the present invention from incidental, typically one bend shapes of the prior art. In another sense, the present invention contemplates advertently "**developing**" a shape which will function (once overcoated) as a spring in the wire.

In many of the embodiments described hereinbelow, the wire is configured to have a shape that commences in a particular direction (typically away from the surface of the substrate), then bends in one direction, then bends in another direction, then finishes in the same particular direction from whence it commenced (i.e., away from the surface of the substrate).

Figure 2 shows a wire 202 (compare 102) which has had its free end 202a (compare 102a) bonded within a defined contact area 210 (compare 110) on a surface 208a (compare 108a) of a substrate 208 (compare 108), according to any of the techniques described with respect to **Figures 1, 1A, 1B, 1C-1E or 1F** (or other techniques, as described hereinbelow). An initial position of the capillary 204 (compare 104) is shown in dashed lines. A final position of the capillary 204 is shown in solid lines. The surface 208a of the substrate 208 lies in an x-y plane (although the overall surface of the substrate is not required to be planar). The final position of the capillary 204 is shown in **Figure 2**, in solid lines, as being displaced from the surface of the substrate in a positive z-direction. The wire 202 is fed from a supply spool 206 (compare 106) through the capillary 204, and is **configured** (to have a shape) in the following manner.

The free (proximal) end 202a of the wire 202 is bonded to the surface 208a of the substrate 208 at a point labelled "a", with the capillary 204 in its initial (dashed line) position. The capillary 204 is then moved along a **trajectory** of points, which are "generically" labelled "b", "c" and "d" in **Figure 2**, to shape the wire in two or in three dimensions.

In the descriptions that follow, for the sake of descriptive clarity, movement of the capillary is discussed as indicative of relative motion between the substrate and the capillary. Often, movements in the x- and y- directions are achieved by moving the substrate (e.g., an x-y table to which the substrate is mounted), and movements in the z-direction are achieved by moving the capillary. Generally, the capillary is usually oriented in the z-axis. However, it is within the scope of this invention that capillaries with many degrees of freedom could be employed to configure the shape of the wire stem.

Generally, movement of the capillary 204 is effected by a positioning mechanism (POSN) 220 under the control of a microprocessor-based controller (CONTROL) 222, and is linked to the capillary 204 by any suitable linkage 224. As will be discussed in greater detail hereinbelow, this permits point-to-point control over the position of the capillary, to describe its trajectory.

As will also be discussed in greater detail hereinbelow, during its traverse of the trajectory, vibratory (e.g., ultrasonic) energy can be supplied to the capillary 204 by a suitable transducer (ULTR) linked 230 to, or mounted directly to, the capillary 204, and operating (e.g., on/off) under control of the controller 222.

As will also be discussed in greater detail hereinbelow,

when the capillary has reached its final (solid line) position, the wire 202 is severed. This is illustrated in **Figure 2** by an electrode 232 positioned adjacent the wire 202 (typically at a fixed position with respect to the capillary 204), the electrode 232 receiving electrical energy from an electronic flame-off (EFO) circuit 234 which is operated under control of the controller 222.

As will also be discussed in greater detail hereinbelow, the operation of severing of the wire (e.g., by electronic flame-off) can be enhanced by providing ultraviolet light directed (e.g., by a lens 236) at the cutoff position (position "d" in **Figure 2**) from an appropriate light source 238. As will be discussed in greater detail hereinbelow, the light (238) can be directed at a cutoff position (d) on the wire (202), or at the electrode (232), or between the electrode and the wire.

In the figures that follow, a number of exemplary configurations for wire stems are described.

Figure 2A shows a wire 202 having its free (proximal) end 202a bonded to a point "a" on a surface 208a of a substrate 208. The capillary 204, shown in a final position (compare **Figure 2** final position) moves along a trajectory of points from "a" to "b", from "b" to "c", from "c" to "d", from "d" to "e", and from "e" to "f". From the point "a" to the point "b", the capillary 204 is moved in the vertical (z-axis) direction. From the point "b" to the point "c", the capillary 204 is moved parallel to the surface 208a of the substrate 208 in the y-axis direction. From the point "c" to the point "d", the capillary 204 is moved in the vertical (z-axis) direction to a position "d" which is more vertically displaced (higher) from the surface 208a of the substrate 208 than the point "b". From the point "d" to the point "e" the capillary 204 is moved parallel to the surface 208a of the substrate 208 in the y-axis direction, opposite to

(i.e., in the minus or negative y-axis direction) the direction in which the capillary 204 moved between the points "b" and "c". This "returns" the capillary 204 to a point ("e") which may (or may not) be directly above its starting point ("a"). From the point "e" to the point "f", the capillary 204 is again moved in the vertical (z-axis) direction. The point "f" is more vertically displaced (higher) from the surface 208a of the substrate 208 than the point "d". As is discussed in greater detail hereinbelow, the wire will be severed at the point "f", resulting in a free-standing wire stem having its proximal end bonded to the substrate and its distal end displaced from the surface of the substrate.

This movement of the capillary 204 along the trajectory a→b→c→d→e→f imparts a U-shape to the wire 202. It is, of course, assumed that the wire 202 is sufficiently ductile (e.g., formable) to acquire a shape (e.g., U-shape) which substantially conforms to the trajectory of the capillary. This U-shape is considered to be exemplary of two-dimensional forming of the wire.

As will be discussed in greater detail hereinbelow, the preferred materials for the wire will exhibit small, but noticeable, amounts of springback which must be accounted for in the trajectory of the capillary 204 to impart a desired shape to the wire. As will also be discussed in greater detail hereinbelow, once the capillary 204 has reached its final position ("f"), the wire is severed at (or adjacent to) the capillary 204.

Figure 2B shows a wire 202 having its free end 202a bonded to a point "a" on a surface 208a of a substrate 208. The capillary 204, shown in a final position (compare **Figure 2** final position) moves along a trajectory of points from "a" to "b", from "b" to "c", from "c" to "d", from "d" to "e", from "e" to

"f", from "f" to "g", and from "g" to "h". From the point "a" to the point "b", the capillary 204 is moved in the vertical (z-axis) direction. From the point "b" to the point "c", the capillary 204 is moved parallel to the surface 208a of the substrate 208 in the y-axis direction. From the point "c" to the point "d", the capillary 204 is moved in the vertical (z-axis) direction to a position "d" which is more vertically displaced (higher) from the surface 208a of the substrate 208 than the point "b". From the point "d" to the point "e" the capillary 204 is moved parallel to the surface 208a of the substrate 208 in the y-axis direction, opposite to (i.e., in the minus or negative y-axis direction) the direction in which the capillary 204 moved between the points "b" and "c". This "returns" the capillary 204 past a point ("e") which is not (but which may be) directly above its starting point ("a"). From the point "e" to the point "f", the capillary 204 is again moved in the vertical (z-axis) direction. The point "f" is more vertically displaced (higher) from the surface 208a of the substrate 208 than the point "d". From the point "f" to the point "g", the capillary 204 is moved parallel to the surface 208a of the substrate 208 in the y-axis direction, opposite to (i.e., in the positive negative y-axis direction) the direction in which the capillary 204 moved between the points "d" and "e". From the point "g" to the point "h", the capillary 204 is again moved in the vertical (z-axis) direction. The point "h" is more vertically displaced (higher) from the surface 208a of the substrate 208 than the point "f". As is discussed in greater detail hereinbelow, the wire will be severed at the point "h", resulting in a free-standing wire stem having its proximal end bonded to the substrate and its distal end displaced from the surface of the substrate.

This movement of the capillary 204 along the trajectory a→b→c→d→e→f→g→h imparts an S-shape to the wire 202. Again, it is assumed that the wire 202 is sufficiently ductile (e.g.,